NONLINEAR INTERNAL WAVES IN THE SOUTH CHINA SEA DURING ASIAEX

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OUTLINE:

0 Satellite Coverage and Analysis of RADARSAT SAR Images

0 Internal Wave Distribution Maps in SCS from SAR images during ASIAEX-2001

0 SAR and Mooring Data Comparison and Integration on May 9-10, and May 4-5, 2001

0 Environmental Parameters and Data Assimilation by Numerical Model

0 Wave-wave Interaction on May 18, and May 4, 2001 from SAR Imagery

0 Summary of the Characteristics of Internal Waves in SCS during ASIAEX

0 Implication of Internal Wave Effects on Acoustic Propagation

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Satellite Coverage and RADARSAT ScanSAR Images in SCS

- On January 25, 2001 ERS-2’s gyro#1 failed, and Taiwan Ground Station can no longer process SAR images.

- In replacement, all cloud-free SPOT images (60km * 60km) with 20m resolution were collected and processed in near-real time during ASIAEX from Taiwan Ground Station.

- Most of days during ASIAEX, SPOT images were obscured by the cloud-cover and internal waves were visible only on May 7 and May 14, 2001.

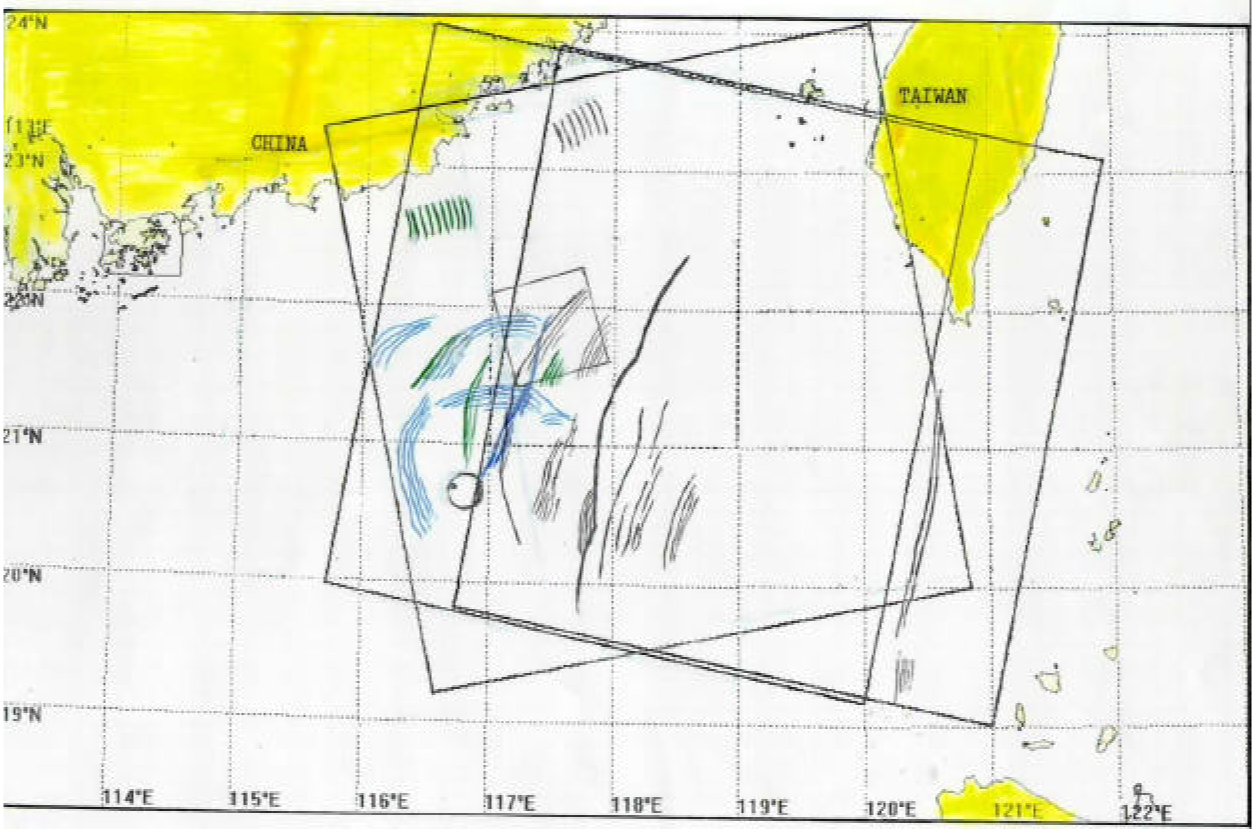
- Four RADARSAT ScanSAR images (500km * 500km) from May 2, May 9, May 18, and May 11 (replaced by June 4) have been collected during ASIAEX through RADARSAT International.

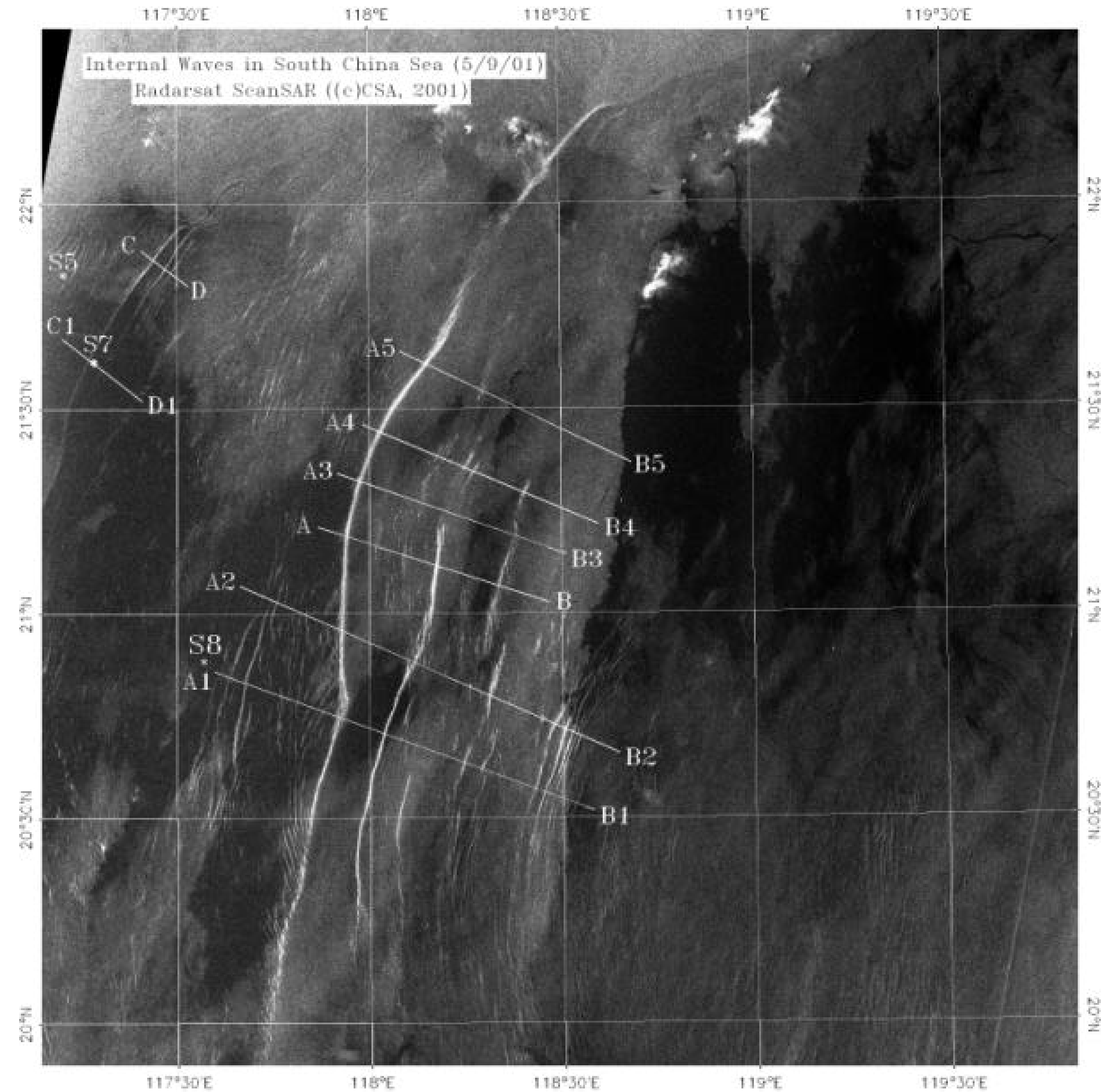
- On May 11, due to transmission problem the SAR data were lost (Typhoon?).

- RADARSAT Standard SAR images (100km * 100km) from April 17, 18, 24 and May 1, 4, 5, 19, 26, 28, 2001 have been collected during ASIAEX through NRL and NOAA Satellite Active Archive (SAA).

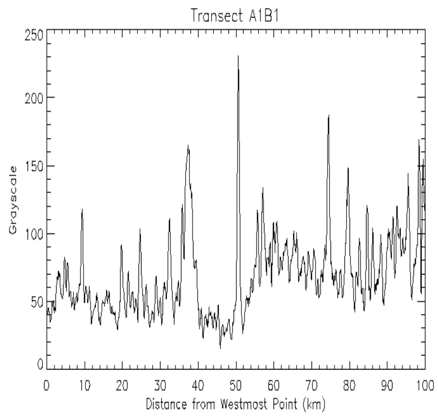
Internal Wave Distribution Map from RADARSAT in the South China Sea during ASIAEX-2001

Antony K. Liu, NASA/GSFC





Internal Waves in South China Sea (5/9/01)
Radarsat ScanSAR ((c)CSA, 2001)
117°30'E
118°E
118°30'E
119°E
119°30'E
22°N
21°30'N
21°N
20°30'N
20°N
S5
C
D
C1
S7
D1
A5
B5
A4
B4
A3
B3
A
B
A2
B2
S8
A1
B1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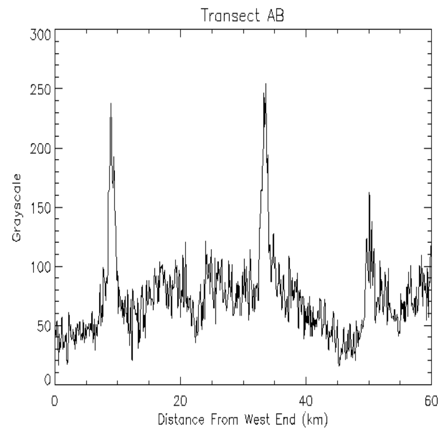
Distance from Westmost Point (km)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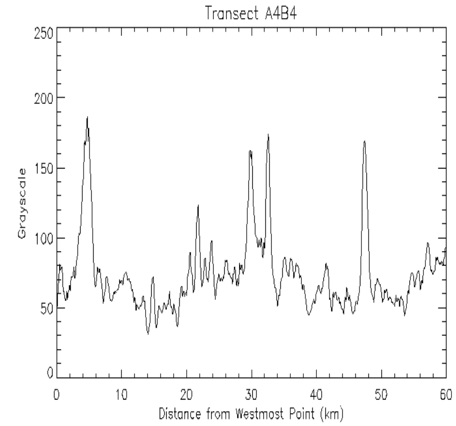
Distance From West End (km)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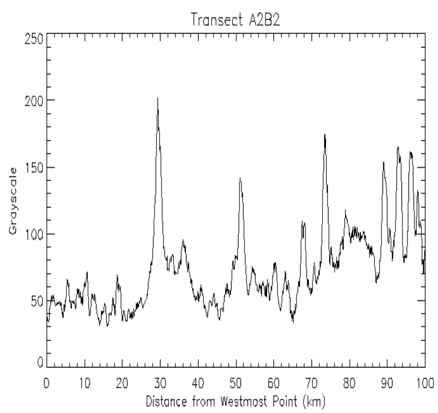
Distance from Westmost Point (km)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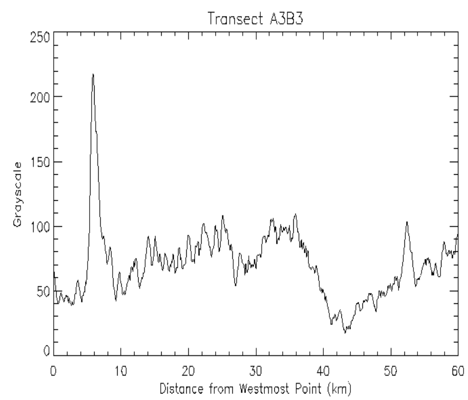
Distance from Westmost Point (km)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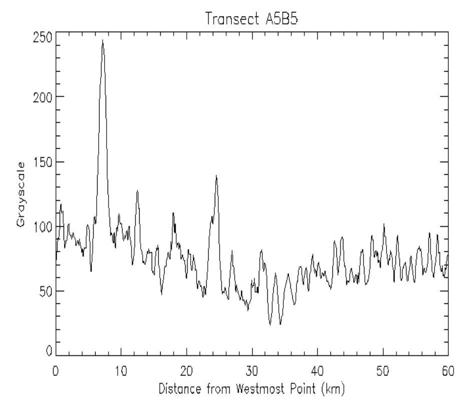
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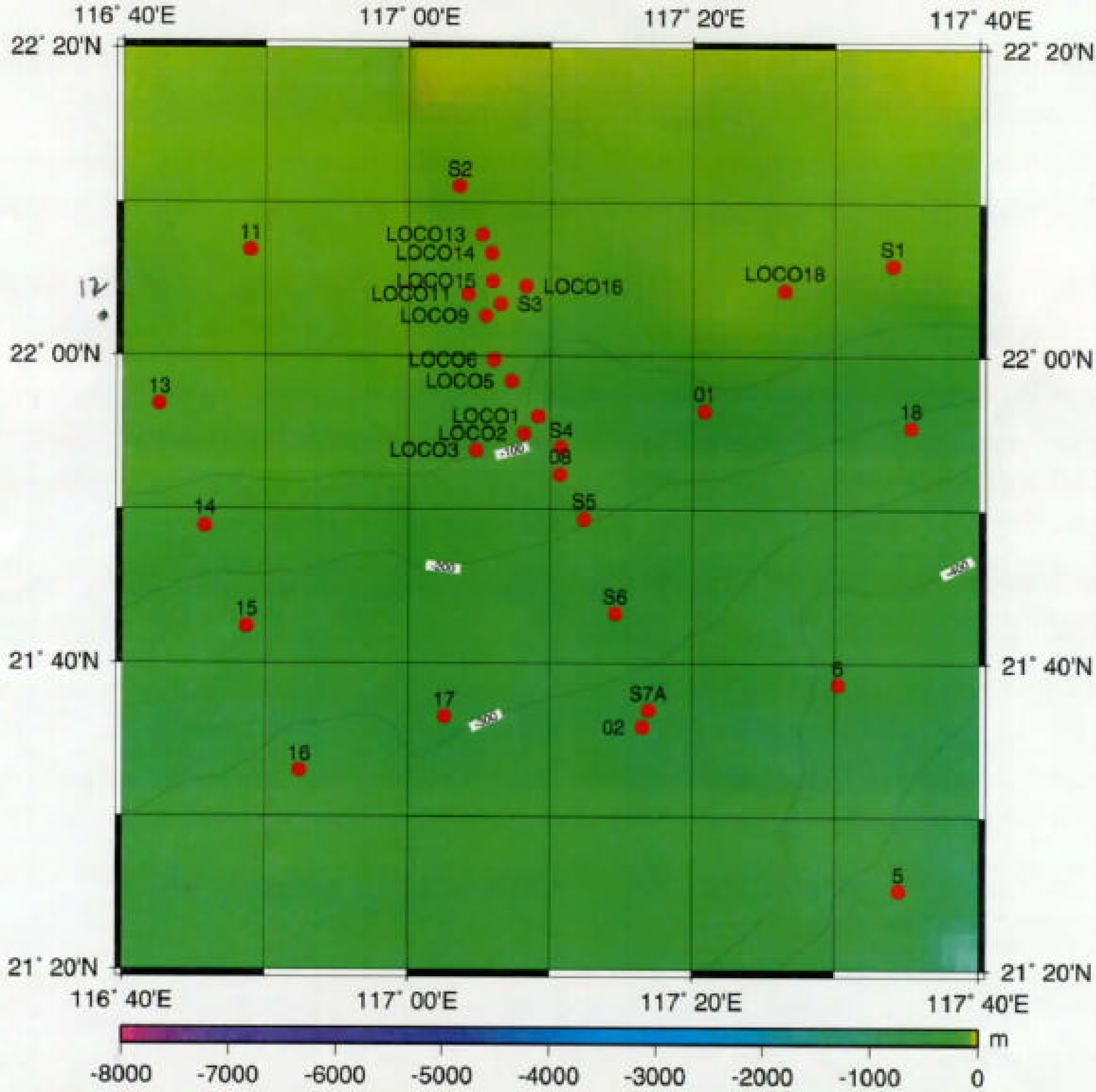
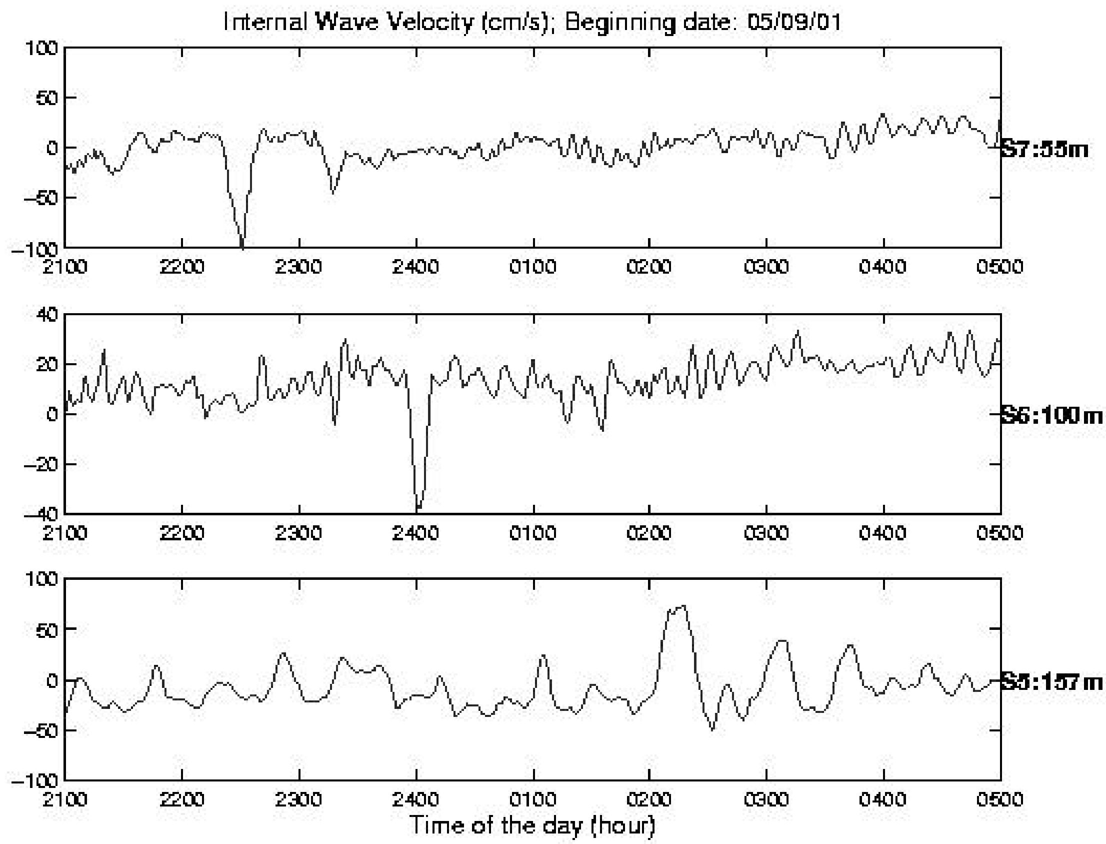
Distance from Westmost Point (km)

ASIAEX CTD Stations





Internal Wave Velocity (cm/s); Beginning date: 05/09/01
S7:55m
S6:100m
S5:157m
100
50
0
-50
-100
40
20
0
-20
-40
2100
2200
2300
2400
0100
0200
0300
0400
0500
Time of the day (hour)

SUMMARY OF SAR AND MOORING DATA COMPARISON (May 9-10)

SENSOR (ADCP)	S2		S4		S5		S6		S7		S8	SAR
DEPTH (m)	71		120		184		275		350		800	---
DISTANCE (km)		34.1		8.5		12.9		12.0		88.1		
SHIFT TIME (min)		762		162		134		91		415		744
		---		160		132		91		468		
IW DIR (deg)	75/85		45		45		25/5		25		---	28
MOOR DIR	16		16		16		16		16			
SHIFT DIST (km)		33.1		7.4		10.0		6.2		44.1		76
IW SPEED (m/s)		0.72		0.76		1.24		1.14 (1.54)		1.77		1.70
	(0.33)			0.77		1.26 (1.14)		1.14		1.57 (1.75)		
IW WIDTH (km)	---		0.7		1.5		0.9		1.4		---	1.4
					1.6		1.5		1.4			2.5
							(0.8)				(0.7)	
SOLITON #	---		---		3		3		3		5	3
IW LENGTH (km)	---		1.2		2.4-1.6		4.2-1.6		4.4-2.1		9.7-2.4	4.3-2.8
					7.6-1.8		10.4-2.4		10.5-3.6		7.9-2.5	13.3-5.2
CURRENT (m/s)	0.3		0.5		0.9		0.6		1.2		---	---
	---		0.4		1.2		0.8		1.6		---	---
AMPLITUDE (m)	---		---		(80/90)		(32/63)		(70/95)		---	---

SUMMARY

0 Satellite Remote Sensing Is Critical to Several Aspects of ASIAEX, Including Tracking Internal Waves, and Locating Fronts, Especially the Synoptic 2-D Internal Wave Pattern in the Test Area.

0 Comparison of RADARSAT ScanSAR and Mooring Data Show Good Agreement and Consistent Internal Wave Field with Marine Radar Images and Model Results on May 4-5, and 9-10, 2001.

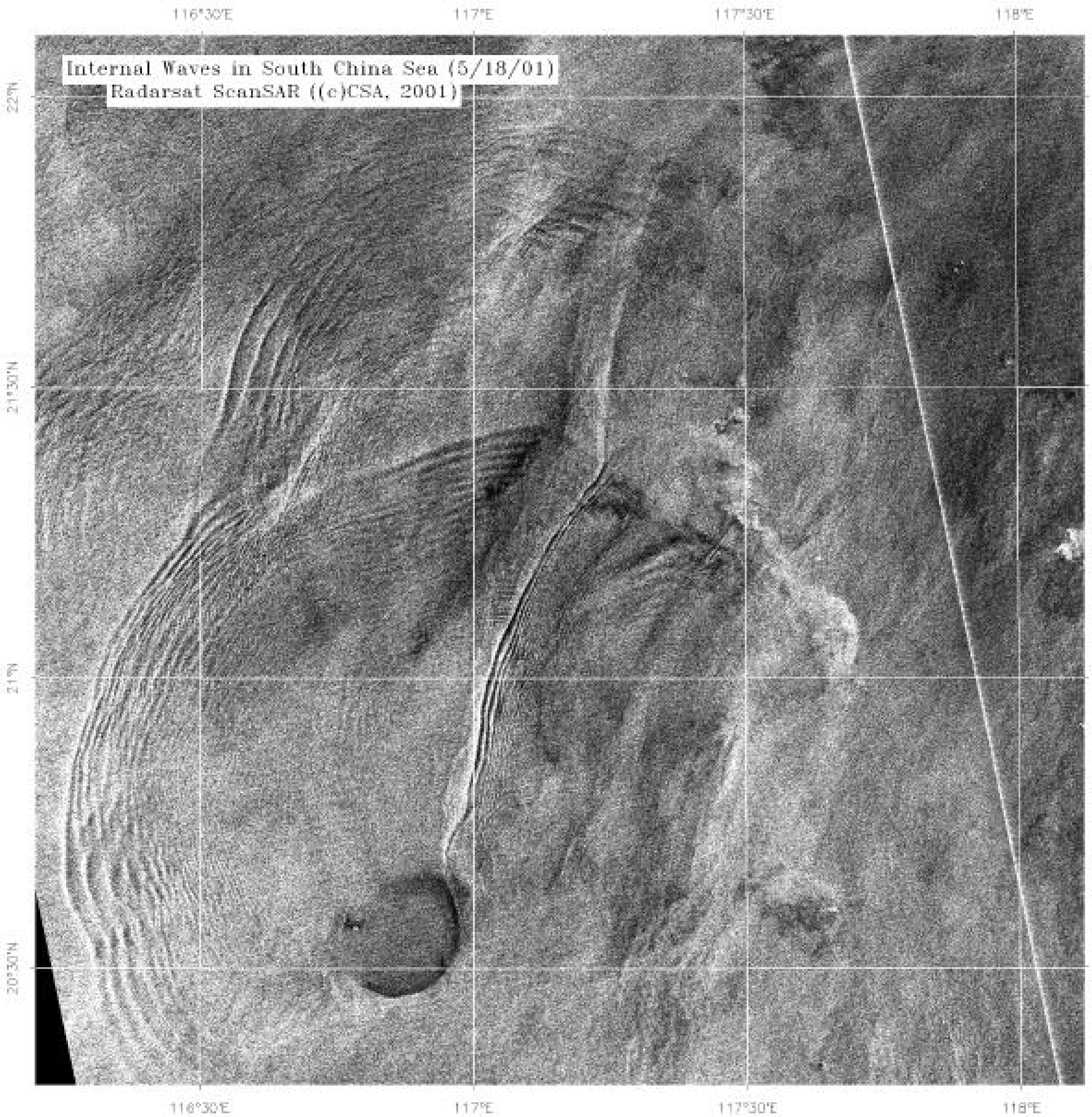
0 Remote Sensing and Mooring Data Can Be Integrated by Numerical Simulations from Deep Ocean (SAR) to S5/6/7 (Mooring) on Shelf Using Modified KDV-Type Internal Wave Evolution Code.

0 Typical Internal Wave Characteristics:

- Water Depth and Density: 800 m to 70 m and CTD Data
- Internal Wave Direction: 25^o to 75^o (Ray Tracing Method)
- Internal Wave Speed: 1.7 m/s to 0.7 m/s
- Soliton Width: 1.5 km to 0.7 km
- Soliton Number: 5 to 3 to Wave Train
- Soliton Separation: 9.7 km and 2.4 km to Wavelength of 1.2 km
- Wave Amplitude: 95 m to 32 m
- Dissipation: Eddy Viscosity up to 5 m^2/s

0 Wave-Wave Interaction Has Been Observed on May 4 and 18, 2001 in ASIAEX Test Area and Is Very Important for Acoustic Applications (Two-Dimensional Effects).

WAVE-WAVE INTERACTION



SUMMARY OF SAR AND MOORING DATA COMPARISON (May 4-5)

SENSOR (ADCP)	S2	S3	S4	S5	S6	S7	S8	SAR
DEPTH (m)	71	85	120	184	275	350	800	---
DISTANCE (km)		15.1	19.0	8.5	12.9	12.0	88.1	
SHIFT TIME (min)		---	420	67	117	84	----	744
		---	---	59	122	78	437	
IW DIR (deg)	90	80	75	55*				13
			15	45*	5	25		10
MOOR DIR	16	16	16	16	16	16	16	
SHIFT DIST (km)		15.0	19.0	8.0				
			9.8	6.1	8.5	6.2	38.6	56
IW SPEED (m/s)	(0.35)	---	0.75	2.00*	1.21	1.23	---	---
				(0.77)	(1.18)	(1.72)		
	(0.33)		----	1.72*	1.16 (1.14)	1.32	1.47 (1.55)	1.26
			(1.43*)	(1.10)	(1.63)	(1.72)		
IW WIDTH (km)			0.7	0.8	1.2	0.8	0.8	1.5
				(0.8)			(0.7)	
SOLITON #	Packet	---	3	2	3	1	1	2
IW LENGTH (km)	0.2	---	1.3-1.0	2.1	1.9-1.5	---	---	2.0
CURRENT (m/s)	---	---	---	0.3	0.3	0.3	---	---
	0.3	---	0.5	0.7	0.6	0.5	---	
AMPLITUDE (m)	---	---	---	---	(16/32)	---	---	---

* Effects of Wave-Wave Interaction

MODEL OF NONLINEAR INTERNAL WAVE EVOLUTION ON SHELF

0 Evolution Equation of Wave Amplitude A (x,t) with Variable Coefficients

$$A_t + C_o A_x + aAA_x + bA_{xxx} - eA_{xx} = 0\,,\;\; U(z) = C_o A_o f'(z)$$

0 Eigen-Value Problem for Vertical Modes

$$f'' + [N^2 - w^2] f / C_o = 0\,,\;\; f(o) = f(-H) = 0\,,\;\; C_o = w/k$$

0 Environmental Parameters

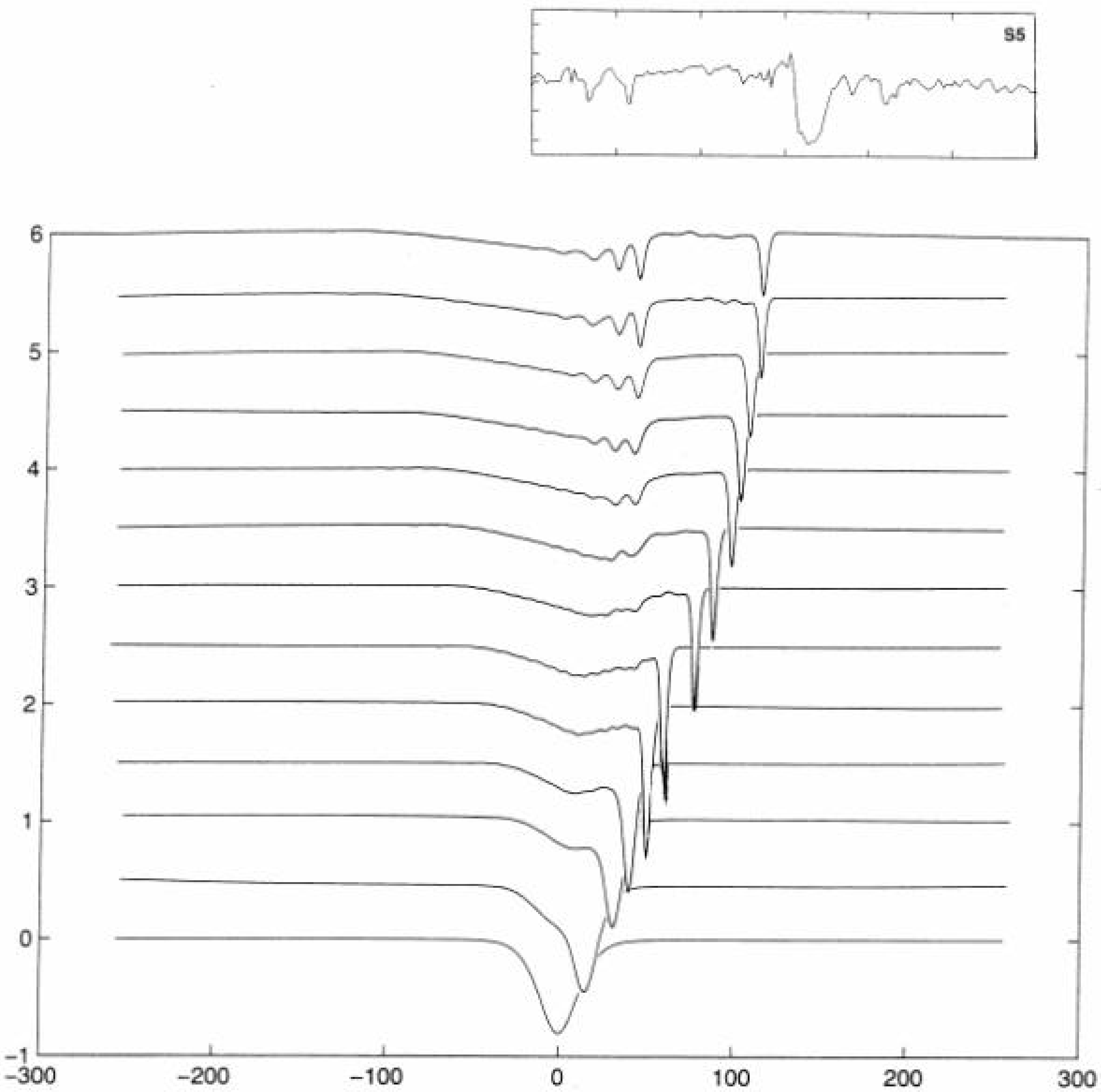
Nonlinear: $a = 3C_o \int_{-H}^{0} f'^3 dz \Big/ 2\int_{-H}^{0} f'^2 dz$

Dispersion: $b = \int_{-H}^{0} f^2 dz \Big/ 2\int_{-H}^{0} f'^2 dz$

Dissipation: e - Eddy Viscosity

0 Numerical Simulations
- FFT in Spatial Coordinate
- Centered Divided Difference for Time Derivative
- Window Filter at the Computation Boundary
- Initial Waveform as Inputs from Field Data

NUMERICAL SIMULATION OF WAVE EVOLUTION



ACOUSTIC IMPACT OF INTERNAL SOLITONS

0 Resonance Coupling Effect
- Strong Horizontal Gradient in Sound Speed Induced by Internal Solitons
- Coupling between Acoustic Normal Modes

0 Time Spreading
- Differences in Acoustic Modal Group Velocities Cause Time Spreading of Pulses.
- Interference Patterns between Mode Multipaths Are Very Sensitive to Coupling Events.
- Significant Temporal Variation in Arrival-Time

0 Transmission Attenuation
- Coupling of Mode-1 into Higher Modes due to Soliton Packet
- In General, Attenuation Is Greater for Higher Modes
- Energy Sink and Significant Variability in Apparent Attenuation for Low Modes

0 Internal Soliton Parameters
- Soliton Number, Soliton Location, Soliton Direction, Soliton Wavelength, and Wave Packet Length
- More Soliton Activity Closer to Receiver, the Greater the Spreading and Bias in Arrivals

0 Two-Dimensional Effects
- Variability of Environmental and Soliton Parameters on Shelf in the ASIAEX Area
- Soliton Evolution Path Is not Aligned with Source and Receiver
- Wave-Wave Interaction